10/10 Nice work

Lab 4: Self-homodyne DFB Linewidth Measurement

MAT288S Optoelectronics Measurements

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Introduction:

The DFB laser source output was delayed far past its coherence length and recombined in a Mach-Zender Interferometer (MZI). The recombined signal was detected on an electrical spectrum analyzer (ESA) and oscilloscope to determine the laser linewidth as shown in figure 1.

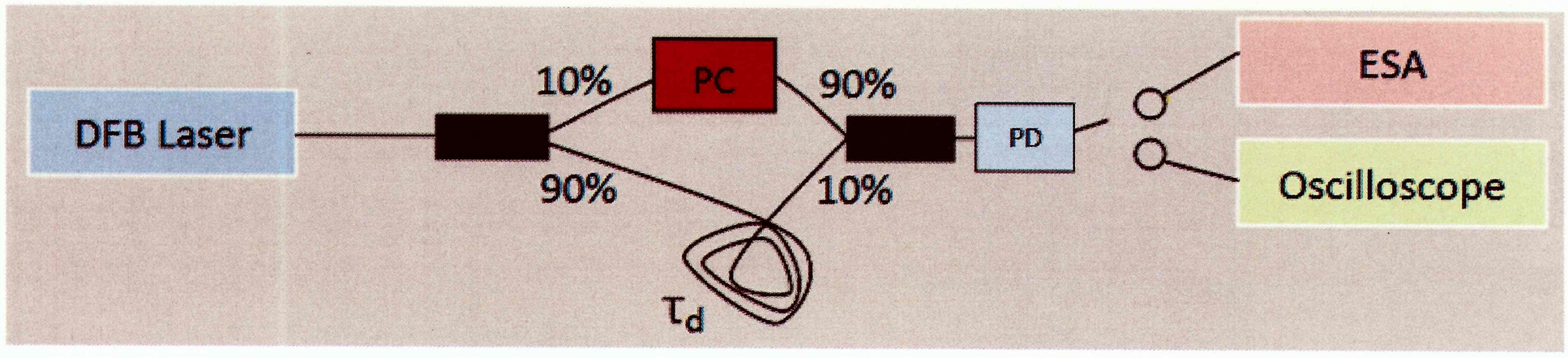

Figure 1: Self-homodyne linewidth test set-up

Fiber lengths were attached to one of the sides of the MZI to provide variable delays. The two 10/90 splitters in the MZI path add ~10dB insertion loss. The optical power measured before the photodetector (PD) was -7.5dBm, with a power difference of ~0.3dB between the MZI arms. The PD was unbiased to reduce noise.

Experiments and Discussion:

(1) The function generator is connected to the ESA and set to 10MHz with a variety of wave shapes. The sinusoidal input produces a 0dBm peak at 10MHz along with much lower amplitude harmonics at 20, 30, 40, 50MHz. This is due to a non-ideal output from the signal generator producing additional tones. When switched to a square wave the odd tones increase (i.e. 30, 50, 70MHz) while the even tones are unchanged as expected from the Fourier series. When we switch to the triangular wave the odd harmonics are again higher than the sinusoid but not as large as for the square wave. +2

Figure 2: 10MHz sinusoidal (left), triangular (center), square wave (right) ESA plots

(2) The noise of the ESA was calculated as a function of resolution bandwidth by leaving the input port open. The graph of the noise dependence on the resolution BW is shown in figure 3 along with the calculated thermal noise power from the 50 ohm termination with a bandwidth equal to the resolution BW. As the graph shows, the ESA noise floor is about 40dB above the ideal limit at the thermal noise floor. +2

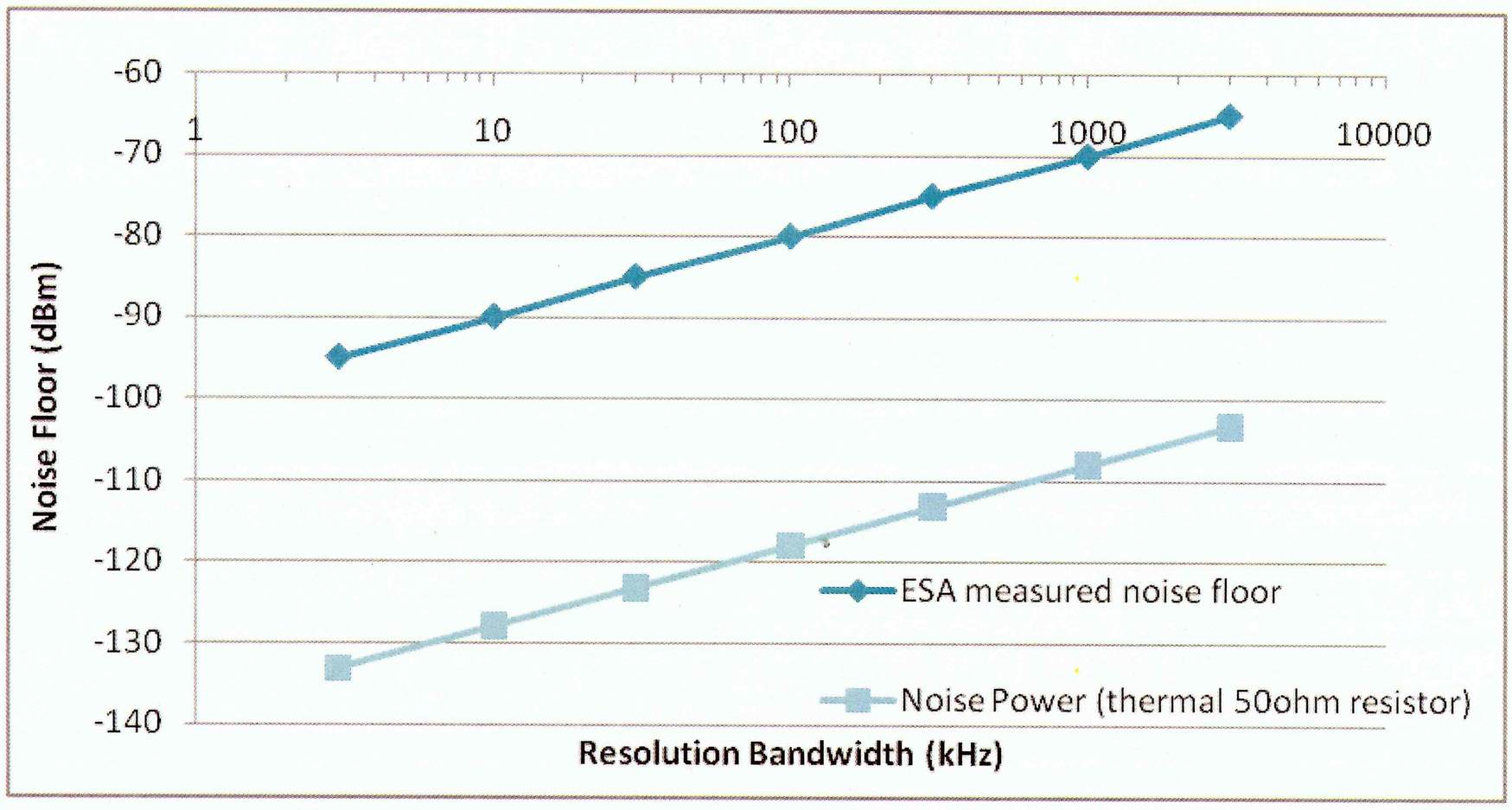

Figure 3: Noise floor vs. resolution bandwidth

(3) The set-up is configured as shown in figure 1 with the PD connected to the oscilloscope and the path lengths matched. As the fiber in one MZI path is jiggled the phase delay in that arm is varied and the oscilloscope output fluctuates from 0-10mV due to the changing interference; this also occurs without jiggling the fiber due to room vibration but this occurs very slowly (<10Hz). The magnitude of these oscillations is reduced as the polarization controller shifts one MZI leg to the other polarization; now the two MZI paths are at different polarization and cannot interfere so the oscilloscope output is a constant 10mV. As we disconnect one MZI, the output is stationary at 5mV regardless of jiggling the line as we would expect now that the interferometer has an open arm. We now realign the MZI arm polarization and add additional fiber to one side; the

+2

oscilloscope output oscillates more rapidly when we add fiber delay as the two MZI arms become more incoherent, constructive and destructive interference happen at random phase overlap as shown in figure 4. 100m: more rapid fluctuations from larger total path to be disturbed; lower amplitude from lower coherence?

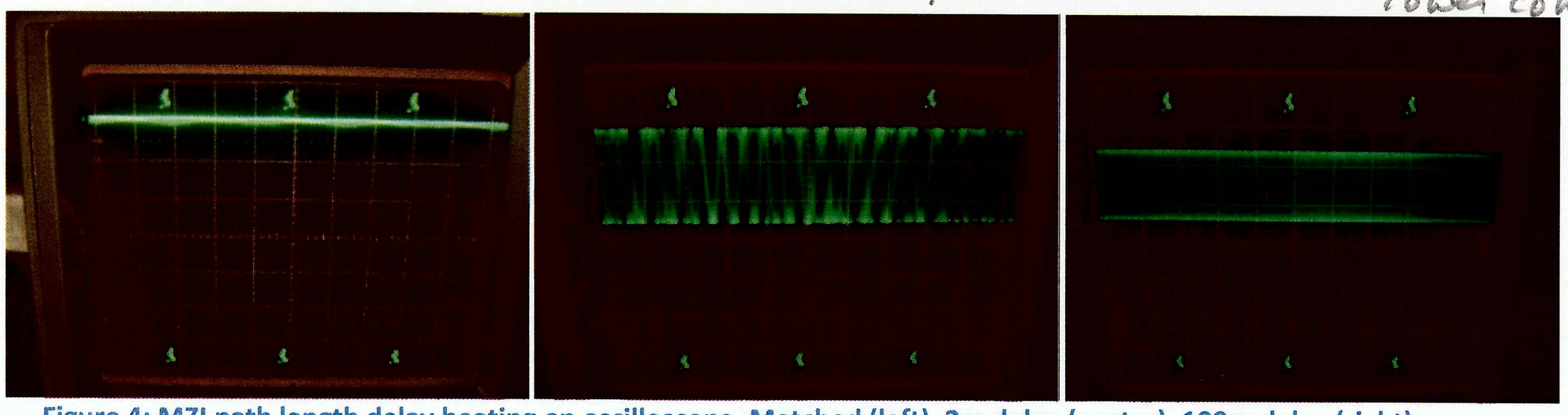

Figure 4: MZI path length delay beating on oscilloscope. Matched (left), 2m delay (center), 100m delay (right)

(4) The linewidth of the DFB laser was measured by adding delay in one of the MZI arms such that the two paths of the MZI were incoherent. When the MZI is balanced only DC noise in the ESA appears as shown in figure 5. With 18m of delay, the linewidth begins to show but it is non-Lorentzian with multiple side-lobes indicating that the difference in the two MZI paths is still not very incoherent as shown in figure 6a. With 100m of delay, the FWHM on the ESA can be calculated to be 6.52 MHz as shown in figure 6b. However, as discussed in "Photonics" by Yariv and Yeh on pg. 495, for the case where the delay is longer than the coherence time of the laser the ESA linewidth is NOT the DFB linewidth but is in fact twice.[1,2] With this in mind, the true DFB linewidth measured with a 100m delay MZI is 3.26MHz. The FWHM was also measured using 25km of fiber to be 12.92MHz on the ESA corresponding to a 6.46MHz DFB linewidth as shown in figure 6c; the peak in the linewidth measurement is also shifted from 500kHz for the 100m delay (see figure 6b) to 1.5MHz with some distortion in the Lorentzian like linewidth. The slight distortion in the ESA spectrum and the increase in the DFB linewidth found using the 25km delay line might be attributed to the effects of a slow frequency drift in the laser source adding a low MHz beat noise when combined with a delayed (frequency shifted) incoherent version of itself.

Thanks

?

The coherence time and length of the DFB laser were calculated to be:

$$\tau_c = \frac{1}{\pi * dv} = 98ns, \quad L_c = \frac{c*\tau_c}{n} = 20m \qquad \text{(for 100m delay)}$$

$$\tau_c = 49ns, \quad L_c = 10m \qquad \text{(for 25km delay)}$$

Therefore both 100m and 25km fiber delays were in the limit $\tau_d \gg \tau_c$, and the 18m fiber delay was close to the coherence length, which is why the ESA spectrum from this

[1] A. Yariv and P. Yeh, Photonics, Oxford University Press, Oxford, 2007, p. 495.

[2] H. Ludvigsen, M. Tossavainen, M. Kaivola, "Laser linewidth measurements using self-homodyne detection with short delay," Optics Communications **155**[1-3], 1 October 1998, pp. 180-186.

measurement showed the linewidth with added sub-peaks. Both 100m and 25km delay measurements provided the delay limit $\tau_d \gg \tau_c$, and both measurements imaged the laser source against an incoherent version of itself. However, the 25km delay line shows more distortion from a Lorentzian-like linewidth (even though the 100m shows some distortion too as visible in figure 6b) so the 100m delay might be the better choice to measure linewidth. +2

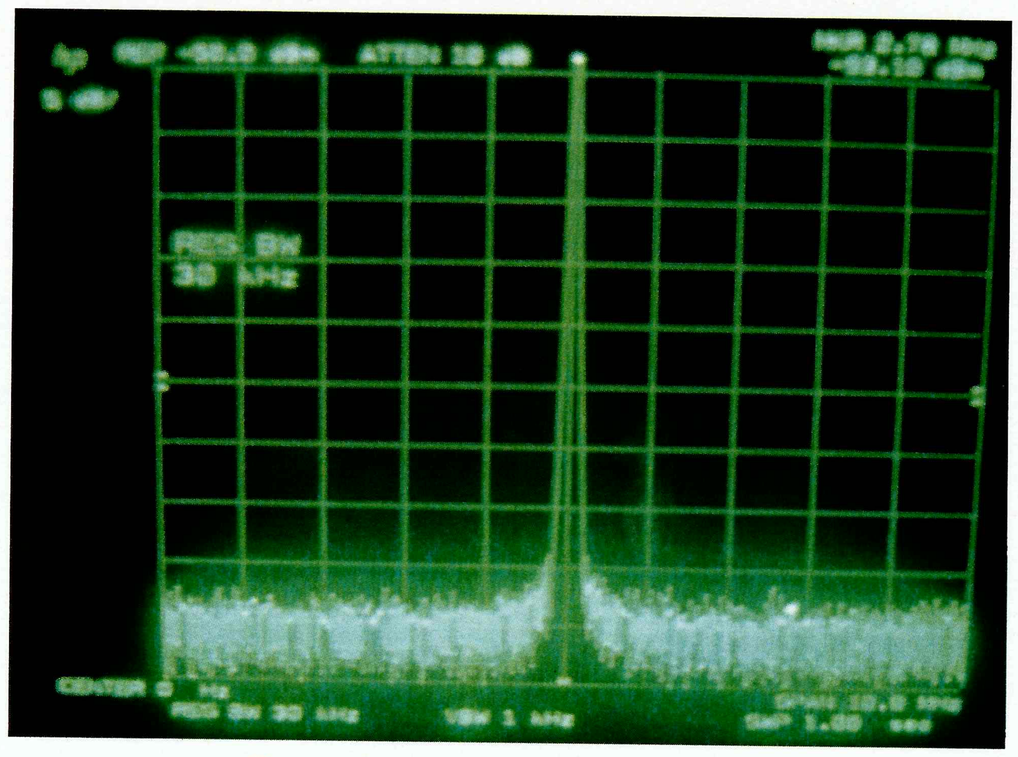

Figure 5: ESA DC noise spectrum

shift from Ø
+ asymmetry -
real or ESA artifact
?

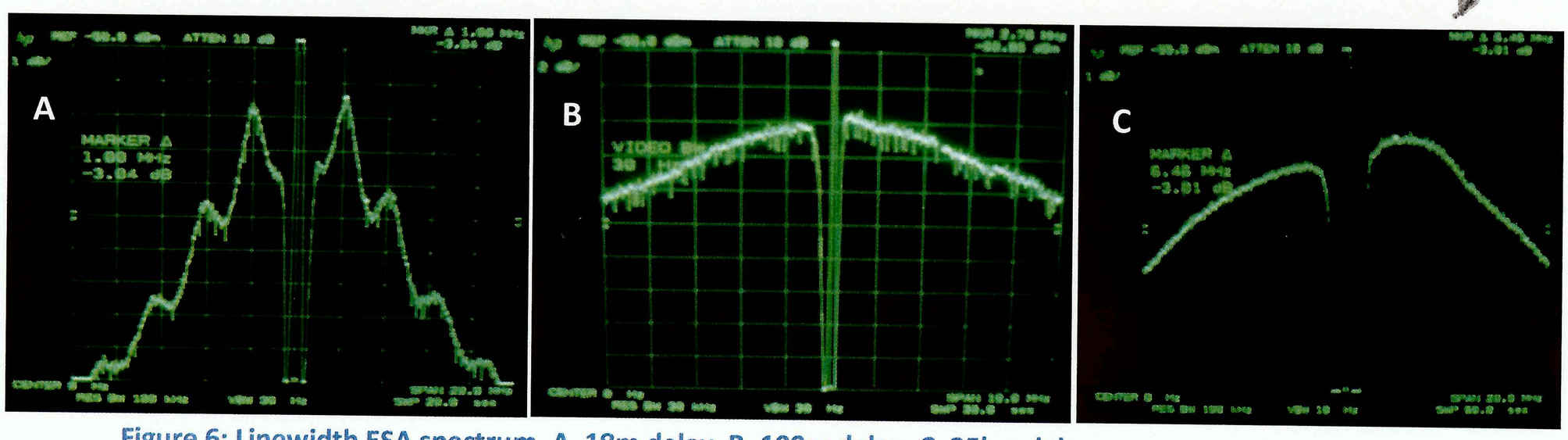

Figure 6: Linewidth ESA spectrum. A. 18m delay, B. 100m delay, C. 25km delay.

(5) The MZI is balanced again and used to calculate the fiber length inside the DFB laser box. One leg of the MZI is unscrewed slightly from the mating ferrule to provide a reflection thereby inducing an external cavity next to the DFB as shown in figure 7. The second leg of the MZI does not affect the measurement (as tested in ESA) and is not shown in figure 7.

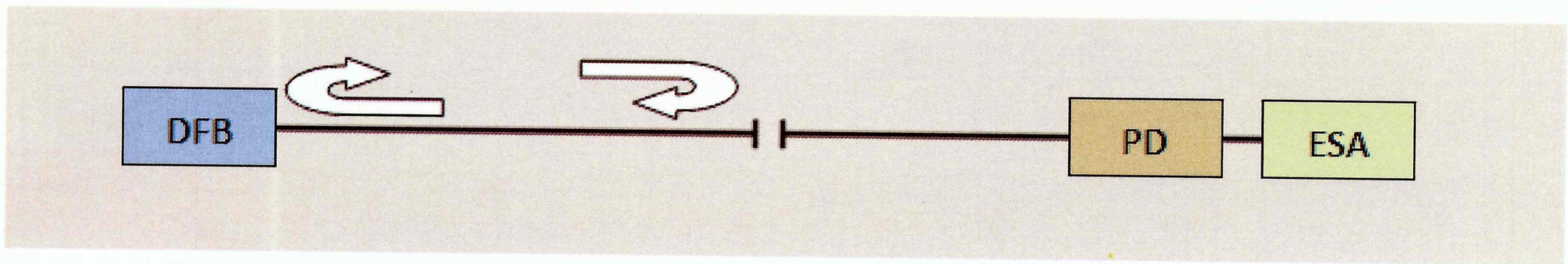

Figure 7: Optical reflection set-up

The ESA spectrum was recorded for path lengths from the DFB to the external reflection point of 3.2m, 4.2m, and 5.2m as shown in figure 8. The measured free spectral range of the external cavity for these three lengths is shown in table 1 along with the calculated expected length and fiber length in the DFB box.

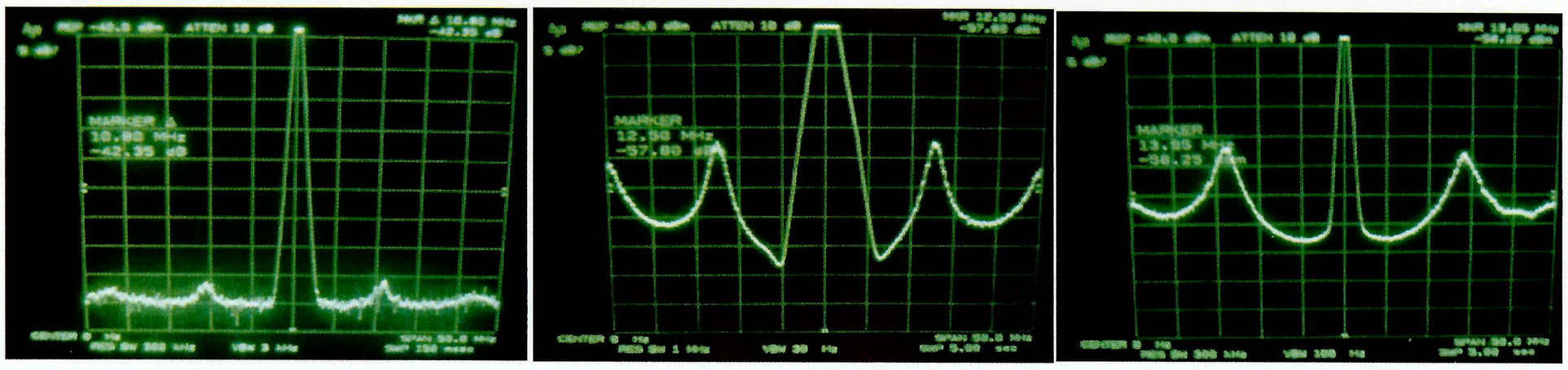

Figure 8: ESA spectrum measurements of external cavity free spectral range. 5.2m fiber (left), 4.2m fiber (middle), 3.2m fiber (right).

Table 1: External cavity measurement results

Measured FSR (MHz)	Corresponding cavity length (m)[3]	Measured external-to-DFB box length (m)	Calculated Internal-box length (m)
10.8	9.6	5.2	4.4
12.5	8.3	4.2	4.1
14	7.4	3.2	4.2

Based on the calculated internal-box lengths, the estimated length of fiber inside the DFB box is ~4.2m.

+2 Nice.

[3] Calculation based on Lcavity=c/(2*n*df)